Project: **1206**

Project title: **High-resolution modeling of the interaction of physical and biogeochemical processes in the Kara Sea**

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Report period: **2023-11-01 to 2024-10-31**

The current Project is aimed on the study of hydrodynamics and biogeochemical processes of the Kara Sea by means of numerical modeling. We use a specially-developed MITgcm-based (Marshall et al., 1997) regional high-resolution **Ka**ra **S**ea **M**odel (**KASM**) with effective horizontal resolution of 1500 m, which allow to resolve the first baroclinic Rossby radius and simulate the mesoscale and submesoscale eddy dynamics explicitly almost everywhere in the Kara Sea except for the vicinity of the Ob and Yenisey estuaries.

During the current stage of the Project, we were predominantly working on the refinement of the tidal dynamics in KASM in order to simulate the total circulation of the Kara Sea on the intra-diurnal time-scales realistically. We were also focused on coupling KASM with a more sophisticated marine biogeochemical model than that previously used.

The work plan for 2024 included: (1) Study of the eddy dynamics in the marginal ice zone in the Kara Sea, investigation of the generation, evolution, transport and dissipation of mesoscale and submesoscale eddies with the horizontal sizes reliably simulated with the model KASM. (2) Study of the interaction of physical and biogeochemical processes in the Kara Sea, with a particular focus on marginal ice zone and during the bloom in the first part of summer.

In the following we briefly report our main results obtained during the current stage of the Project:

Investigation of eddy dynamics on small spatial and temporal scales requires taking into account tidal motions since they can generate considerable shear stresses thus producing instabilities and corresponding turbulent motions. Though tidal motions had previously been incorporated in KASM, but after additional verification carried out during the current stage of the Project, we found that the quality of the tidal motions' simulation in KASM is still insufficient.

Therefore, we have reconfigured the KASM's tidal module and generated new open boundary conditions for tidal motions using the regional barotropic tidal model of the Arctic Ocean Arc2kmTM (Howard and Padman, 2021). To simulate tidal motions with KASM realistically, we specify the amplitudes and phases for seven main tidal harmonics in the Kara Sea, namely M2, S2, K2, N2, K1, O1, and P1, along the open lateral boundaries. After some tuning and calibration, the tidal charts produced with KASM have become much more realistic and reliable. For example, figure 1 demonstrates the comparison between the external solution produced with the Arctic model Arc2kmTM and with reconfigured KASM.

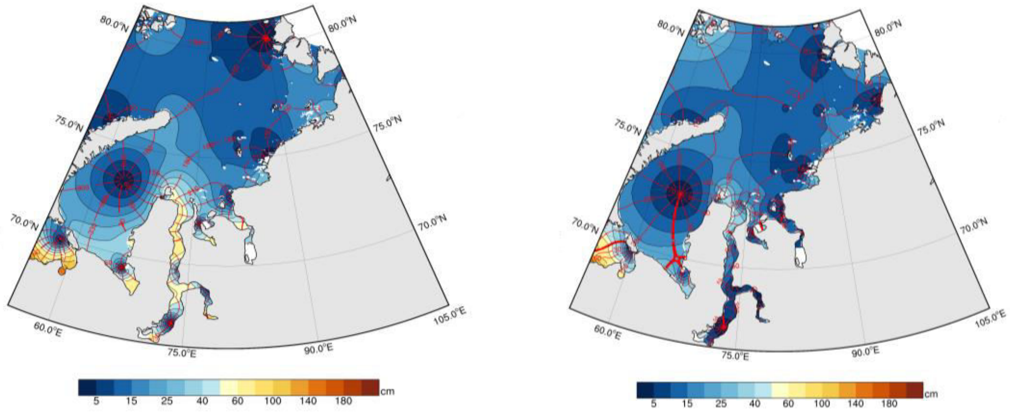

Fig. 1. Tidal chart of M2 tide, red lines – phase (degrees), black lines – amplitude (cm). Left – Arc2kmTM results; right – KASM results.

Though the amplitudes are somewhat smaller on the KASM's M2 tidal chart than in Arc2kmTM, their spatial distribution is very similar to that observed in the Arc2kmTM solution. Moreover, verification of KASM's solution against observational sea level data at numerous gauges along the coasts show that KASM's solution is better than that produced by Arc2kmTM. We can see almost all amphidromic points in the KASM's solution at their correct locations.

Phases are also quite reliable, especially around the main amphidromic point located in the south-west part of the Kara Sea. This result is in good agreement with earlier independent research focused on tidal dynamics in the Kara Sea presented in (Kagan and Sofina, 2018).

We have carried out simulations with hourly output for the spring–summer period of 2021 in order to reproduce and investigate the eddy dynamics during the period of sea-ice melting. Figure 2 presents the surface field of current velocity and relative vorticity $\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$ divided by the Coriolis parameter $f = 2\Omega \sin\phi$, where Ω – Earth angular velocity, ϕ – latitude. This parameter ζ/f can be used to detect vortex structures in the spatial field of horizontal current velocities. Figure 2 shows eddies that appear near the boundaries of the ice cover and in the frontal zones formed by river runoff. Currently we are working to compare our results with satellite observational data, but even now we can already conclude that the eddy patterns obtained in our results look realistic and resemble results reported in other studies aimed on research of eddy dynamics (e.g., Chang et al., 2015; Wekerle et al., 2020).

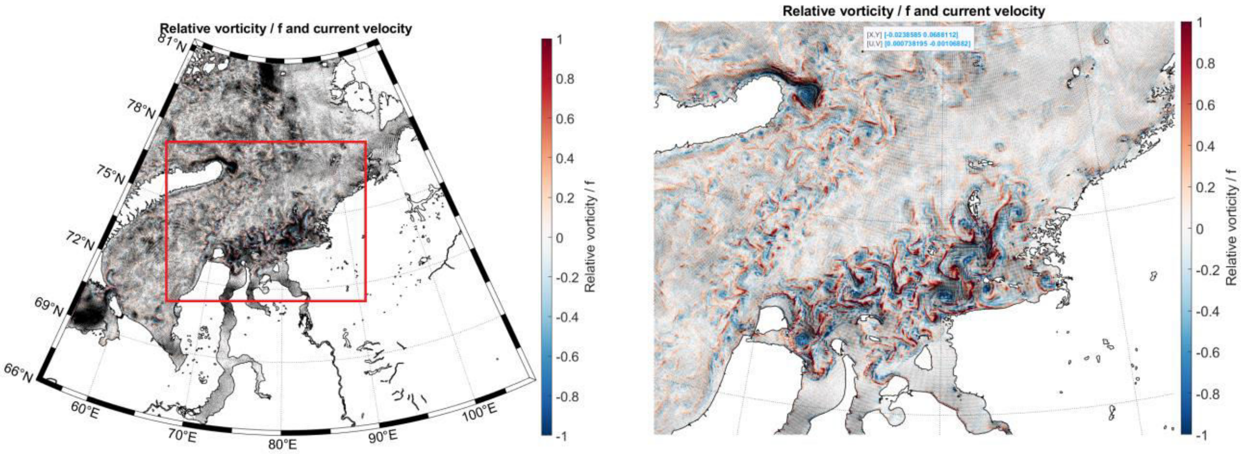

Fig. 2. Simulated field of current velocity at the sea surface (black arrows) and calculated relative vorticity divided by the Coriolis parameter on 30.06.2021. The figure on the right-hand side is a zoom for the area indicated with a red rectangle on the left.

Due to the problems with the relatively simple 7-component marine biogeochemical model ECO7 we were previously using (these problems were discussed in the last report for 2023), currently we have decided to switch to a more sophisticated marine ecosystem model named SPBEM, which incorporates a larger number of nutrients, two phytoplankton types, dissolved organic matter, and a more complex benthic sub-model. This model was previously used for other Arctic seas and showed good results. Thus, we believe that it can be successfully configured for the conditions of the Kara Sea, which is a really challenging region for marine biogeochemical modeling due to strong riverine input of nutrients, turbidity, change of phytoplankton types spatially and temporally, etc. The work of coupling KASM with SPBEM and tuning of the model is currently ongoing.

References:

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